Vertical Navigation (VNAV)

NAC Task 20-2 Report

To be presented to the NextGen Advisory Committee

June 21, 2021

Table of Contents

Executive Summary

When Vertical Navigation capability (VNAV) was introduced in aircraft equipage, it brought a fundamental change to the National Airspace System (NAS). VNAV offers a host of improvements to aircraft operations, ranging from safety enhancements to improved efficiencies. By far, VNAV's greatest benefit was the ability to fly stable, vertically guided approaches to all runway ends. Prior to VNAV, only the Instrument Landing Systems (ILS) provided vertical guidance to touchdown.

In the NextGen era, efficiency and reduction of carbon emissions are added VNAV benefits, captured by enabling idle descent paths on terminal arrival procedures and participating in Established on RNP (EoR) operations at airports with widely spaced runways. VNAV also enables more resilient low visibility approaches when an ILS facility is out of service. The presence of LNAV and VNAV on an aircraft implies that the operator is no longer dependent on a ground-based Navigation Aid infrastructure. More and more, industry has innovated new solutions through which VNAV improves airline operations.

At the time of this report, there are approximately 7,351 Title 14, Code of Federal Regulations (14 CFR) part 121 aircraft, roughly 1,245 of which lack VNAV capability. Seventy-four percent of these aircraft are regional aircraft. While regional jets were hailed as a "game-changer" for passenger comfort, being able to fly quieter and higher than the turboprops they replaced, they were also equipped with avionics similar to those turboprops, which flew low and slow. This lack of advanced equipage left the small regional and older mainline aircraft unable to realize VNAV benefits.

While many aging mainline aircraft continue to be retired, this is not the case with the 50-seat regional jet. Many will operate through this decade and, lacking VNAV capability, continue to present a barrier to safe, stable approaches and achievement of key NextGen benefits.

Some of the key impediments to VNAV upgrades include: continual threat of aircraft retirement, cost of avionics, lack of perceived Return on Investment (ROI), and the nature of mainline/regional short-term capacity purchase contracts. These impediments have translated to increased pilot workload, lack of efficiency, and reduced safety when ILS is out of service or not offered at an airport.

It’s also worth noting that while the focus of this report is on VNAV capability, many aircraft without VNAV also lack other key NextGen capabilities. This group encourages the reader to also review the NAC Tasking 19-01, Minimum Capabilities List (MCL), to better understand the impediments caused by equipage gaps.

Introduction

The FAA's Next Generation Air Transportation System, or NextGen, is a complex airspace modernization effort, requiring the collaboration of many stakeholders in pursuit of "emphasizing safety, increasing efficiency, improving environmental performance, and enhancing the customer experience."[1] This report is the official response to a NAC tasking that seeks to understand barriers to the use of VNAV, as they have become a stumbling block to further implementation of Performance-Based Navigation (PBN) procedures in the National Airspace System (NAS).

Background

PBN is an advanced, satellite-based form of navigation which creates precise 3D flight paths from takeoff to landing. The flight paths an aircraft is permitted to fly depend on its avionics capabilities, both laterally and vertically. While the concept of lateral guidance is more intuitive (that is, what path we fly from A to B), vertical guidance concerns when an aircraft climbs or descends, and how fast. Vertical guidance is useful in optimizing climbs and descents, minimizing environmental impact, and reducing greenhouse gases. It also provides guidance on how low an aircraft can descend in the clouds when trying to land.

Where legacy Instrument Landing Systems (ILS) provide guidance based on radio navigation signals transmitted from the ground, PBN Area Navigation (RNAV) approaches rely on Distance Measuring Equipment (DME) or Global Navigation Satellite System (GNSS) positioning for lateral guidance, and barometric altimeter systems for vertical guidance. This guidance is internal, calculated by the aircraft's Flight Management System (FMS) computer.

The "quality," or fidelity, of internal guidance is based on the capability of the aircraft computer and its validation process. While older equipment is often only capable of providing Lateral Navigation (LNAV) guidance, newer aircraft also provide Lateral Navigation + Vertical Navigation (LNAV/VNAV) guidance. Localizer Precision with Vertical (LPV) guidance offers even more accuracy due to an

[1] "What is NextGen?" Federal Aviation Administration (FAA), May 26, 2021, https://www.faa.gov/nextgen/what_is_nextgen/.

additional Global Positioning System (GPS) enhancement. Applying the familiar "good/better/best" comparison to these categories, LNAV (or LNAV Only) guidance = "Good," LNAV/VNAV guidance = "Better," and LPV guidance = "Best." (Figure 1)

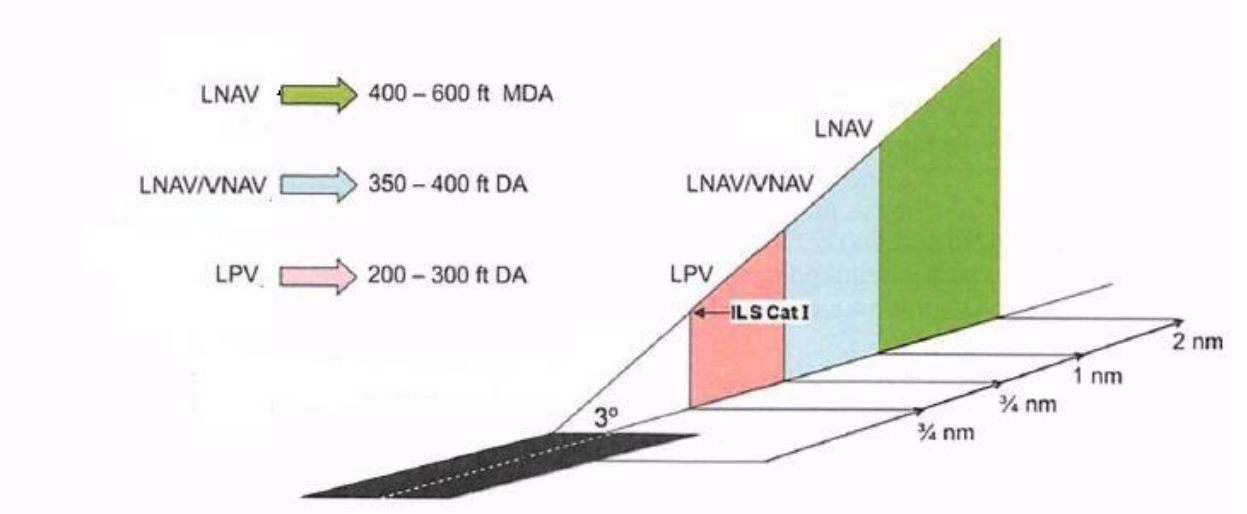


Figure 1

The Issue

Most major U.S. airports employ multiple runways to maximize arrival and departure capacities. Termed "simultaneous parallel operations," these airport configurations are complex. Two or more streams of arriving and departing aircraft require precise navigation, both lateral and vertical, in addition to active engagement with terminal approach controllers.

Due to this complexity, the FAA's criteria for evaluating Terminal Instrument Procedures (TERPS) during simultaneous parallel operations prohibits the use of LNAV Only guidance on RNAV approach procedures.

So, what does this mean? What is the impact of this? Two things:

1) Aircraft with less-capable LNAV guidance systems cannot execute RNAV (GPS) instrument approaches when multiple runways are in use. Often, the only alternatives are either an ILS approach (ground-based guidance) or a visual approach. If it's a cloudy/foggy day and the aircraft is operating in Instrument Meteorological Conditions (IMC), then visual approaches are not an option. If an ILS system is inoperative on a parallel runway on this same cloudy day, then an LNAV aircraft requires "special

handling" to land on the other ILS-equipped runway. At some airports where there are concentrations of LNAV aircraft, this creates "friction," creating more work for controllers, increasing risk, and slowing airport operations.

2) RNAV approaches are critically important to realizing NextGen benefits. RNAV procedures offer flexibility for aircraft to avoid noise-sensitive and environmental areas. They also can shorten airport approach patterns, saving time and fuel while increasing predictability in the NAS. Airports are beginning to deploy RNAV (RNP) approaches in a highly efficient configuration termed, "Established on RNP," or EoR. In this configuration, LNAV Only aircraft are unable to "mix in" with VNAV aircraft due to the TERPS constraint. The result is that LNAV aircraft cannot fly EoR approaches with most of the other traffic, resulting in more track-miles, time, fuel, noise, and emissions. Additionally, due to the complexity of managing multiple arrival flows, one LNAV aircraft often drags multiple, VNAV equipped aircraft behind it on a much longer, less efficient path. This negates any PBN benefit not only for itself, but also for many aircraft behind it.

This report will examine this "equipage gap" in vertical guidance capability between those capable of providing LNAV/VNAV or LPV vertical guidance, and those which provide only LNAV lateral guidance.

Tasking and Deliverables

On August 10, 2020, the FAA requested the NextGen Advisory Committee (NAC) provide advice on Vertical Navigation. Tasking 20-2, Vertical Navigation (VNAV) was the result.

Tasking Language

"The NAC is tasked to provide the FAA with an industry plan to address the existing equipage gap that prevents the full use of Required Navigation Performance (RNP) approaches for parallel operations. Currently, simultaneous operations cannot be used effectively by operators or air traffic control without a high participation rate. This change will allow the FAA to move forward and unlock larger safety and efficiency benefits associated with initiatives such as, Performance-Based Navigation (PBN) paths to final approach and Established on RNP (EoR).

The NAC advice should include the following:

- *A comprehensive assessment of mainline and regional airline impediments to equipage for full VNAV operations.*
- *Achieve consensus on a plan to eliminate impediments to equipage for VNAV operations.*
- *Where complete consensus cannot be achieved, identify those operators or industry organizations which cannot come to consensus agreement and provide a minority opinion on any objections.*

Scope:

- *FAA will provide the SMEs.*
- *MITRE may be used as a trusted clearing house for data (considered sensitive in nature to the operators).*
- *Include other stakeholder organizations to include relevant manufacturers and pilot unions.*
- *Complete work and provide a final recommendation report no later than the Fall 2020 NAC meeting."*

Clarification

In October 2020, the working group sought clarification from the FAA on the tasking with consideration towards the state of the industry.

At that time, the COVID–19 pandemic operational decline had drastically changed the commercial fleet. Many operators had more than 70 percent of their fleet in storage, and the scope and timeline of an aviation industry recovery was uncertain.

Operator finances were constrained. All major airlines were operating in a negative revenue environment. Scant remaining resources were focused on moving aircraft to and from storage and mandatory aircraft maintenance. Consequently, most operators were not in a financial position to consider equipment upgrades, as even pre-COVID upgrade efforts already underway were halted to preserve cash.

As industry's status was so fluid and its future unpredictable, a tasking response would be limited to those barriers existing prior to the COVID event.

These questions arose:

- How relevant would a response be based on pre-COVID fleet analysis after the drastic impact on the fleet and operator resources?
- What new impediments might the COVID-induced decline have introduced?

We regarded the impact of COVID on the commercial fleet as a potential game-changer. Any plan or conclusions drawn from pre-COVID impediments might be incomplete, inaccurate, or incompatible in a post-COVID market. We just didn't know what would happen.

Therefore, we focused on the present and considered how the working group could meaningfully respond considering the circumstances. After consultation with NAC leadership, we arrived at the following deliverables, which were reported to the NAC on November 17, 2020.

20-2 Vertical Navigation Updated Tasks

- Current Equipage Landscape
- Review of LNAV Aircraft
  - Models

  - Quantities
  - Retirement Plans
  - Upgrade Options Available
- Impediments to Equipage

Process and Development

Described below is the VNAV working group's process to identify relevant aircraft and select operators whom we would poll.

Plan of Attack

The working group sought to poll the operators of LNAV Only aircraft as to their plans for upgrading vertical navigation capabilities. From preliminary data, we targeted a group of 18 "impactful" operators whom we would engage, each of which operated ~ 20 or more affected aircraft. These represented ~ 85 percent of the estimated total LNAV Only fleet.

14 CFR Part 129 (foreign) and 14 CFR Part 135 operators were initially considered; however, their data was ultimately excluded from consideration due to the high foreign fleet equipage rate (~ 92 percent) and less concentrated nature of Part 135 operations.

Operator Poll Questions

The following polling questions were presented to our targeted operators:

- Validation of Fleet Data
  - Aircraft Model Type
  - Size of Model Fleet
  - Quantity of LNAV-Only Aircraft in Fleet
- Fleet Plan
  - Continue to Operate "Affected" Aircraft for 10+ Years
  - Continue to Operate "Affected" Aircraft for 5–10 Years
  - Plan to Retire "Affected" Aircraft in less than 5 Years
- Plan for Implementation of LNAV/VNAV or LPV
  - In Plan
  - Not in Plan
  - Undecided
  - Not Applicable
- If in Plan, Likelihood to Equip within 5 Years
  - Likely
  - Not Likely

  - Not Sure
- If Not in Plan, Primary Impediments/Rationale
  - High Cost of Solution
  - No Operational Benefit
  - Aircraft Down Time Too Long
  - Other
- Additional Remarks or Comments

Fleet Data

Op Specs Authorized VNAV Capability

We secured fleet data from D085 Op Spec data filtered for Part 121 aircraft.

It reflected a total Part 121 fleet size of 7351 aircraft.

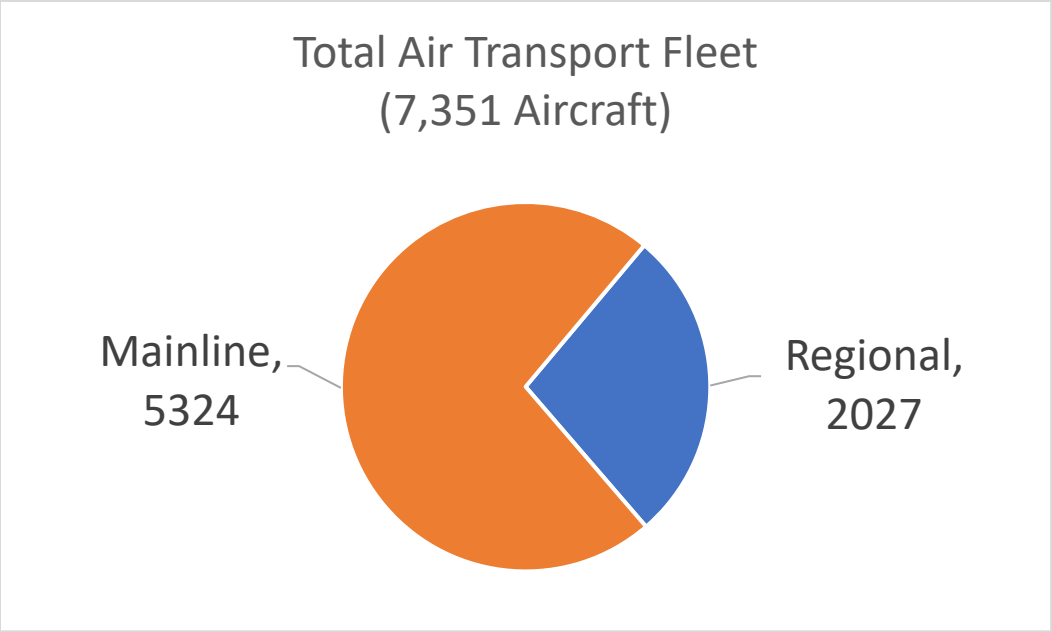
Of that total, 1245 were listed as capable of providing LNAV Only guidance.

More detailed analysis continues below.

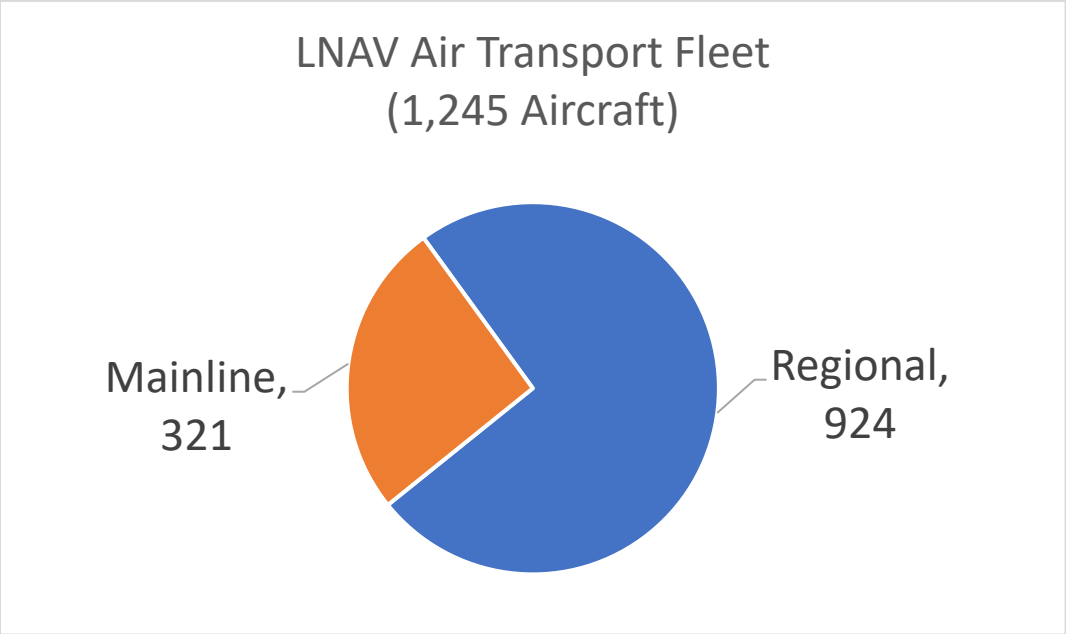
Fleet and Capability Analysis

The statistics regarding Mainline versus Regional airline LNAV aircraft are intriguing.

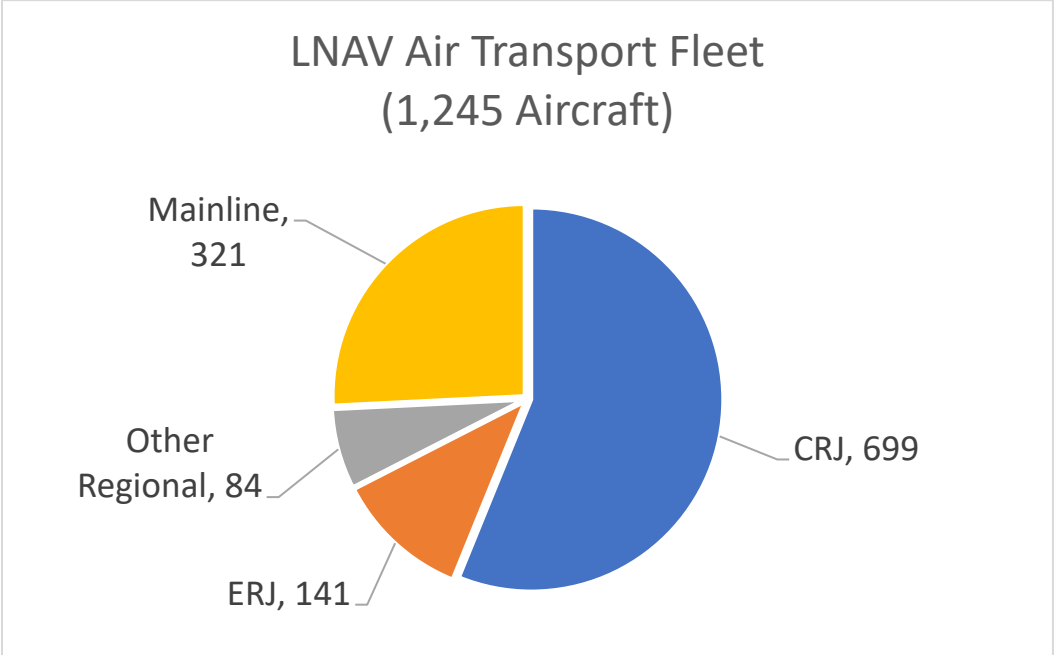
We tallied an approximate total U.S. part 121 fleet of 7351 aircraft: 5324 (72 percent) mainline and 2027 (28 percent) regional aircraft.



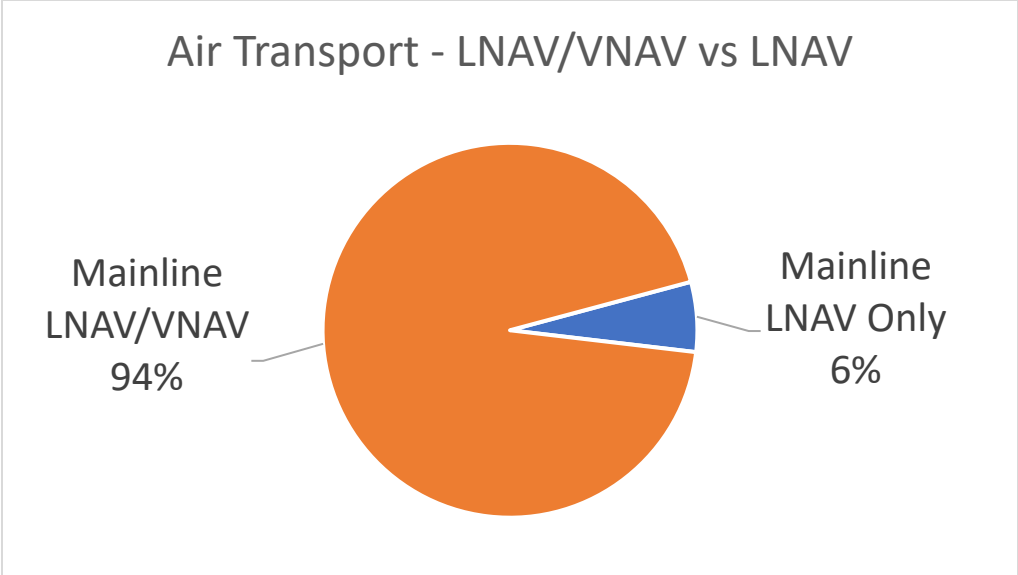
Of the 7351 fleet total, 1245 were indicated as LNAV aircraft: 924 (74 percent) Regional aircraft and 321 (26 percent) larger Mainline types.



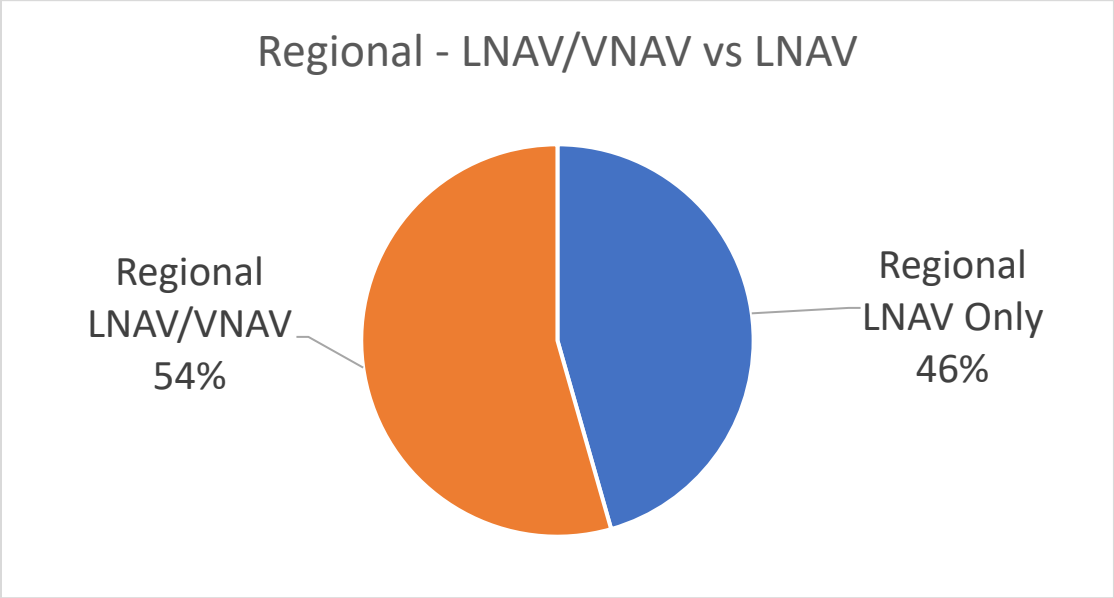
The Regional LNAV fleet can be further broken out by specific aircraft type:



While only 321/5324 (6 percent) of Mainline aircraft are LNAV equipped . . .



. . . 924/2027 (46 percent) of Regional aircraft are LNAV equipped.



These observations reveal two findings:

Finding #1: While Regional aircraft represent only 28 percent of the part 121 fleet, they represent 74 percent of LNAV-equipped aircraft.

Finding #2: Regional aircraft are almost eight times more likely (46 percent versus 6 percent) to be LNAV-equipped than their Mainline counterparts.

Survey Results

MITRE returned the following de-identified operator poll results:

A/C Type	***Pre-COVID LNAV-Only Fleet (Ops Specs)***	**Operator Reported LNAV-Only Fleet**	**Operator Plans to operate>5yr**	**Operator Plans to Equip**
CRJ	*704*	452	431	259
ERJ–135/145	*141*	113	113	0
Other	*408*	69	0	0
Total	*1253*	634	544	259

Assumptions

- The LNAV constraint on simultaneous parallel operations is most commonly observed at larger hub airports. As regional jets have significant operations at hubs, they disproportionally impact those operations as well. Our primary focus will therefore be on CRJ and ERJ operators due to this disproportionate impact.
- Any reference to ERJ aircraft in this analysis concerns only ERJ–135/145 models. As the newer ERJ–170/190 family is more fully equipped, those aircraft have no impact on this issue. No analysis in this document concerns or includes the ERJ–170/190 family of aircraft.
- This effort does not address any possibility that the U.S. Regional fleet may *increase* in future years. Although most new regional aircraft are indeed LNAV/VNAV capable, some new models are not suitable for the U.S. market with regard to labor agreement scope clauses. It is conceivable regional jet operators outside the U.S. may purchase new equipment, freeing up their older LNAV-equipped yet scope-compliant aircraft for deployment in the U.S.

Analysis

- The large decrease in LNAV "Other" aircraft may be largely attributed to mainline MD–80 retirements, under-classification errors in the database, and mainline aircraft operators who did not return a survey response.
- The decrease in CRJ and ERJ aircraft from pre–COVID–19 to the Operator Reported values can be partially attributed to two regional jet operators who did not return a survey response. Another possible cause might reflect post-drawdown retirements.
- Operator plans to retire aircraft may not be conclusively considered as leaving the commercial fleet. "Retired" regional aircraft are often purchased and returned to service by other operators. Considering the recent increased demand for these aircraft to serve smaller markets (ref Additional Perspective), we believe redeployment is more likely than not.

Fleet Impact Conclusions

- Although only 610 of the 845 CRJ/ERJ aircraft were represented in our survey, the fleet size will likely remain closer to its present size due to market trends favoring smaller markets served by these aircraft.

- Approximately 259 (31 percent) are currently planned for upgrade.

Upgrade Solutions

Aircraft and Avionics Manufacturers provided information associated with currently available upgrade solutions. This information focuses on the two most impactful platforms: the Canadair CRJ–200/700/900 and Embraer ERJ–135/145.

Impacted areas associated with upgrade to LNAV/VNAV or LPV capability include:

- Aircraft Systems
  - Flight Management System
  - Displays and Control Panels
  - Flight Director/Autopilot
  - Air Data and GNSS
  - Others, Depending on Configuration
- Simulation and Training
- Technical Publications

CRJ Solutions and Status

- CRJ–200
  - Avionics Manufacturer STC for LPV is Available
  - Autopilot Coupled VNAV is planned, Availability TBD
- CRJ–700/900/1000
  - OEM Service Bulletin for Autopilot Coupled VNAV/LPV is Available
- Challenges
  - Cost of STC and Service Bulletin are Highly Dependent on Aircraft Configuration
  - Component Obsolescence Limits Upgrade hardware availability

ERJ–135/145 Solutions

- Honeywell
  - Upgrade path for ERJ–145 is being developed as contracted by customers to include RNP, LPV, and VNAV capabilities.
  - This will be available for ERJ–145/135 equipped with Honeywell FMS and requires dual installation.
  - Upgrade availability TBD due to COVID delays.

Additional Perspective

Some added perspective was shared in group discussion which better informs the regional equipage issue.

Although LNAV/VNAV capability was delivered as basic on 757/767 and A–320 aircraft in the 1980s, their regional turboprop counterparts were not similarly equipped. Regional operators operated under contract to larger partners and the focus was on efficiency and low cost. When jet aircraft began to replace the older turboprop equipment, the low-cost efficiency model carried over to the newer platforms as 1:1 replacements.

As NextGen didn't begin to take shape until much later, the less-capable LNAV-equipped aircraft encountered no operating issues or impediments. Advanced capability wasn't required, so additional development wasn't demanded of the OEMs either.

This LNAV "stagnation" was overlooked by aviation planners as well, as this technology in regional aircraft largely stood still for a decade until increasing numbers of the LNAV/VNAV equipped EMB–170/190 family began to appear.

Where the COVID–19 pandemic appeared to be accelerating the retirement of the older LNAV aircraft, the characteristics of the recovery now strongly support their market viability once again. Therefore, we cannot rely on forecasts favoring LNAV aircraft retirements.

A more complete version of this discussion can be found in the Appendix.

Impediments to Upgrade

In addition to determining the status of fleet VNAV equipage currently operating in the NAS, the NAC tasking included an assessment of mainline and regional airline impediments to full VNAV operations. To determine this, the survey asked operators to describe the impediments associated with the implementation of LNAV/VNAV or LPV using the following questions in a drop-down menu:

1) Cost of Solution: Cost of existing solutions do not provide favorable return on investment.
2) No Operational Benefit: Benefit associated with LNAV/VNAV or LPV functionality does not warrant investment.
3) Long Aircraft Down Time: Aircraft down time associated with available solutions does not support operational needs.
4) Other: Other impediments exist, please capture any additional information in the Remarks column.

We gathered the following results from seven regional airline survey respondents:

Number of respondents	**Plan for VNAV/LPV**	**If not in plan—primary impediment**	**Likelihood of equipping in next 5 years**
2	In Plan	N/A	
2	Not in Plan	Cost	Not likely
1	Undecided	Cost	Not likely
1	Undecided	—	Not sure
1	Undecided	No operational benefit	Not likely

The cost of upgrading avionics equipment to enable LNAV/VNAV or LPV capability ranges from $75,000 to $350,000, depending on aircraft type, current configuration, and certification type (that is, service bulletin versus STC).

Although only one respondent mentioned an apparent lack of benefit from equipping, it is likely those who cited cost were not persuaded the operational benefit justifies the cost. The following areas could be investigated for potential operational benefits and resulting cost savings over time:

1) Savings from fewer weather diversions, averted by lower approach minima,
2) Time/fuel savings due to avoidance of additional vectoring required during an ILS outage during simultaneous parallel operations, and

3) More efficient climbs and descents if autopilot coupled VNAV (CVNAV) capability is acquired with lowered approach minimum capability.

These operational benefits were discussed by the working group, but it became clear it would require time and effort beyond the scope of this tasking to more clearly establish their applicability and impact on a cost/benefit analysis.

Although the clearly dominant impediment to upgrade was cost of solution, the working group also identified four other relevant impediments.

The Regional Airline—Network Carrier Business Relationship

Unlike the major carriers, which develop and execute their business plans with relative independence, the majority of regional carriers do not own their aircraft, but rather operate aircraft owned or leased by their code-share partner under the constraints of operating contracts. For this reason, the following are impediments to investment:

- Unable to establish ROI due to short length of contract, which precludes investment
- Length of remaining contract time and the region of operation often predicate equipage requirements
- Uncertainty of contract disposition past next renewal date can impede investment
- Competitive nature of the market makes an equipage investment difficult to execute while remaining a competitively attractive business partner
- If the regional airline does not own their aircraft, they are often minimally involved in aircraft equipage decisions, if at all
- Insulation from costs: It often occurs those bearing the cost are insulated from the negative effects of not equipping:
  - If the network carrier purchases fuel, then fuel economy is often not an emphasis item; the network carrier may also not have the granular visibility into their regional partners' operation to identify fuel savings opportunities.
  - If a regional airline is experiencing delays due to insufficient aircraft equipage or holding/vectoring in approach airspace, it may go undetected by their code-share partner if operational performance is within expectational bounds.

- Even if improvement opportunities are identified, the code-share partner may not be collecting sufficiently detailed data to clearly identify and correct the issue.

Training Device Configuration

Another impediment to equipage upgrade involves training support. Some regional carriers own their training devices; however, many purchase training device time from third-party vendors. Training devices can range from desk-top trainers to no-motion procedures trainers and full-flight simulators.

When upgrades to avionics systems require additional crew procedural training, and if the desired configuration is not yet widely available in the industry, the expense of upgrading training devices to the required standard must be borne by the carrier or its code-share partner.

Availability of Upgrade Hardware

Due to the age of manufacture of many of the aircraft types in use by the Regional carriers, there is a limited capability by the avionics equipment manufacturers to upgrade existing equipment due to component obsolescence. This is a significant challenge for two reasons:

1) The cost of re-design is driven by the high specifications associated with development, verification, and certification of aircraft equipment.
2) Unlike consumer products, aerospace avionics manufacturers do not typically justify a business case for components unless it is in association with a new aircraft type. Consequently, the modification of older equipment in legacy fleets becomes more and more difficult as component suppliers eventually abandon their older products to make room for newer equipment lines.

Monetization of Safety Improvements

There are additional safety benefits that accompany LNAV/VNAV capability, which add value but are difficult to quantify in a cost-benefit scenario:

1) In mixed fleets with some advanced vertical navigation capability and some without, there are demonstrated, operational improvements associated with aircraft capable of operating to LNAV/VNAV or LPV minimums.

2) It is widely acknowledged that autopilot coupled vertical guidance commonly available with LNAV/VNAV or LPV capability reduces unstable approaches.
3) The LPV SBAS receiver provides a more accurate present position solution, increasing safety margins in terrain-challenged environments.
4) LPV's lower minimums increase the likelihood of a successful approach and landing.
5) RNP + RF legs may be delivered with some of the modifications and would enable participation in RNAV (RNP) approaches, which simplify and stabilize downwind to final patterns, reducing ATC communications and saving time and fuel.

Final Comments and Closing

This NAC tasking was focused on Vertical Navigation, and specifically requested an assessment for full VNAV operations.

However, the resulting analysis of avionics upgrades made clear that enabling LNAV/VNAV or LPV capability alone does not represent all the capabilities required to fully leverage NextGen benefits. The FAA Minimum Capabilities List (MCL) Ad Hoc Team NAC Task 19-1 Report states on p15 that there are some, "… capabilities which, if absent on an aircraft, could be an impediment to the NAS." These include the following:

- Capability to fly curved Radius to Fix (RF) approach segments,
- Upgraded, resilient position sources,
- RNP position alerting and reporting features, and
- FANS 1/A over VDL Mode 2 Datacomm

The working group agreed that in order to address these requirements, executive leaders would require more specific, supportive benefit data to build a successful business case favoring NextGen equipage investments.

More study in this area is needed and should examine:

- All capabilities required to maximize NextGen benefits,
- How all navigational capabilities work together, including improvements that ensure safety at high density airports and reduce workload risks,
- Operational data from current NextGen implementations, and
- Projected data from planned implementations

The working group also agreed executive leaders will need to see:

- Benefits broken down in terms of which specific equipment provides which capabilities, delivering which benefits;
- Capabilities presented in such a way which will contribute to business analysis, such as where the additional capabilities are most beneficial, where and how cost savings may be achieved, or where markets may become more accessible; and
- Recommendations shaped for decision makers who may be less familiar with NextGen development and its goals.

Any follow-on efforts must draw on the expertise of operators, OEMs, and other stakeholders.

Closing

The working group would like to thank its members for their steadfast participation in its effort to move NextGen forward, and for their diligent collaboration in the development of this report.

Credits and Acknowledgments

VNAV Co-Chairs	Organization
Michael McDowell	Collins Aerospace
Greg Young	Delta Air Lines

Aviation Organizations	Organization
Bill Whyte	RAA

Government Organizations	Organization
Steven Butler	FAA
Chris Hope	FAA
Ayaz Kagzi	FAA
Juan Narvid	FAA
Greg Schwab	FAA
Mark Steinbicker	FAA
Natee Wongsangpaiboon	FAA
Marshall Koch	MITRE
Sean McCourt	MITRE

Labor Organizations	Organization
Darrell Pennington	ALPA
Paul Ryder	ALPA
Doug Willey	ALPA
Brian Townsend	APA

Manufacturers	Organization
Ralf Egalon	Embraer Aircraft
Pierre Marchi	Embraer Aircraft
Erik Ringnes	Honeywell Aerospace
Marc Bureau	Mitsubishi Aircraft
Justin Luo	Bombardier Business Aircraft
Brian Eckmann	Universal Avionics

Operators	Organization
Bret Peyton	Alaska Air
Andrew Benich	American Airlines
Lee Brown	JetBlue
Michael Whitman II	Mesa Air
David Moxham	SkyWest Airlines
Jessica Mulligan	SkyWest Airlines
Gary McMullin	Southwest Airlines
Ron Renk	United Airlines

Glossary of Acronyms and Abbreviations

A-RNP	Advanced RNP
ATC	Air Traffic Control
CAST	Commercial Aviation Safety Team
CFIT	Controlled Flight Into Terrain
CRJ	Canadair Regional Jet
CVNAV	Autopilot Coupled Vertical Navigation
DA/MDA	Decision Altitude/Minimum Descent Altitude
Dep	Departure
DME	Distance-Measuring Equipment
EoR	Established on RNP
Equipage Gap	Difference between Aircraft Equipage/Capabilities
ERJ	Embraer Regional Jet
FMC	Flight Management Computer
FMS	Flight Management System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
IAP	Instrument Approach Procedure
IFR	Instrument Flight Rules
ILS	Instrument Landing System
IMC	Instrument Meteorological Conditions
JSIT	Joint Safety Implementation Team
LNAV	Lateral Navigation
LNAV/VNAV	Lateral Navigation/Vertical Navigation

LPV	Localizer Performance with Vertical Guidance
Mins	Minimums
NAS	National Airspace System (U.S.)
NAC	NextGen Advisory Committee
Nav	Navigation
NextGen	Next Generation Air Transportation System
OEM	Original Equipment Manufacturer
Op Specs	Operations Specifications
PBN	Performance-Based Navigation
RF Legs	Radius-to-Fix (Curved) Approach Segments
RNAV	Area Navigation
RNP	Required Navigation Performance
ROI	Return on Investment
SBAS	Satellite-Based Augmentation System
SME	Subject Matter Expert
STC	Supplemental Type Certificate
TERPS	U.S. Standard for Terminal Instrument Procedures
VMC	Visual Meteorological Conditions
VNAV	Vertical Navigation

Appendix

Historical Perspective: How We Got Here

It's worth a pause to share some historical perspective disclosed in working group discussions.

LNAV/VNAV: Basic Capability or Upgrade?

Many of today's current generation aircraft were developed and purchased in the 1980s. As opposed to Classic 727s and DC–9s equipped with steam gauges and VOR/DME navigation, the 757, 767, and A–320 aircraft were all initially equipped with a digital Flight Management System (FMS) RNAV and electronic displays. LNAV/VNAV was the basic capability, not a selectable option that needed to be cost-justified by fleet managers. These technologies were developed as Boeing and Airbus engineers pushed the envelope on capabilities and delivered them as standard on new aircraft.

This paradigm changed with the advent of regional jets. As opposed to being equipped with new capabilities as an enticement to upgrade older, less capable aircraft, regional jets were developed as simple 1:1 replacements of the turboprop aircraft they were succeeding. One working group member who was then involved in his airline's aircraft selection process recalled his executives wanted, "a turboprop replacement with jet engines on the wings." An attempt at making a case for the benefits of VNAV was attempted but never seriously entertained, as decisions were purely cost-driven in that highly competitive environment.

Another working group member shared their experience while working for a regional jet manufacturer at that time. What minimal technical advances were designed into the aircraft were even sometimes requested to be removed by the customer for cost savings and standardized configuration with the aircraft it was replacing.

The takeaway here is that the LNAV CRJ and ERJ aircraft—which are constrained in today's airspace—were driven to less-capable configurations during a period driven by economic and market pressures. More advanced capabilities weren't offered on these aircraft because operators were asking neither the aircraft nor

avionics Original Equipment Manufacturers (OEMs) for them. The OEMs were simply reacting to their customers' demands at that time.

Failed Expectations

This effect of no demand for improved avionics capabilities failed to meet the expectations expressed by the Commercial Aviation Safety Team (CAST) in their Controlled Flight into Terrain (CFIT) report in 2000. In this "Results and Analysis" report dated June 1 of that year, the Joint Safety Implementation Team (JSIT) identified "Precision-Like Approach Implementation" as one of eight projects. On page 75 of this report, the authors stated, "The increased (operational) capabilities will occur naturally over time, because new production airplanes will come with better equipment installed and Standard or Classic airplanes will be retrofitted or retired. The challenge is to accelerate the introduction of increased capability." This acceleration never materialized as expected.

Where the JSIT expected commercial aircraft to migrate to VNAV-guided 3D approaches, this technological advancement largely stood still in regional aircraft for another 10 years, until increasing numbers of the better-equipped EMB–170/190 began to appear. The "Classic" category of aircraft (as the CAST report refers to them) continued to use the "Constant Angle" technology used by 727s and DC–9s, on which the report commented, "British Airways has been using this for 30 years. It works great."[2]

This JSIT expectation is also conveyed by a "Fleet Migration" graphic. (Figure 2) The timeline for the elements in this graphic was expected to "contribute to the safety goal of an 80 percent reduction in the commercial accident rate by 2007."[3] Although that goal was eventually met with an eventual 83 percent reduction, LNAV–equipped Regional aircraft continued to be delivered nearly 20 years later.

[2] Controlled Flight Into Terrain (CFIT) Joint Safety Implementation Team (JSIT), "CFIT JSIT Results and Analysis," June 1, 2000. p. 54.
[3] Controlled Flight Into Terrain (CFIT) Joint Safety Implementation Team (JSIT), "CFIT JSIT Results and Analysis," June 1, 2000. p. 75.

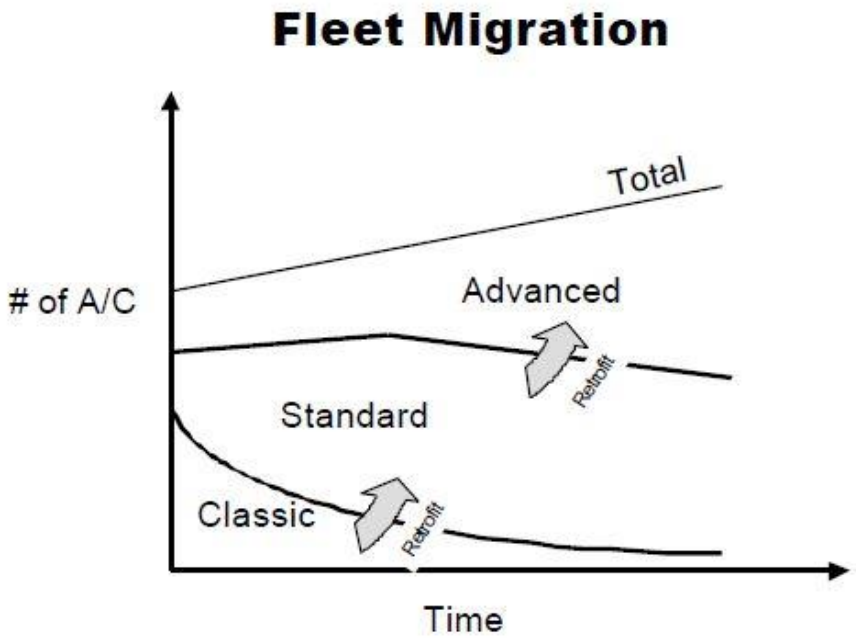


Figure 2

The FAA's "PBN NAS Navigation Strategy 2016" assumes a similar expectation. Table 7 on page 26 of this document clearly defines "RNAV (GPS) approach capability (LNAV/VNAV or LPV)" as a minimum PBN capability for Navigation Service Group 1 airports for the Mid Term. (Figure 3)

Table 7 – Minimum PBN Capabilities

	Near Term (2016–2020)	Mid Term (2021–2025)	Far Term (2026–2030)
Class A Airspace Above FL290	☐ RNAV 2, supported by GNSS or DME/DME	☐ GNSS and DME/DME navigation	
Class A Airspace Below FL290	☐ RNAV 2, supported by GNSS or DME/DME		
Navigation Service Group 1		☐ GNSS and DME/DME navigation ☐ RNAV (GPS) approach capability (LNAV/VNAV or LPV) ☐ RNP 1 capability ☐ RF capability	☐ Time of Arrival Control guidance and automation
Navigation Service Group 2		☐ GNSS and DME/DME navigation	☐ RNAV (GPS) approach capability (LNAV/VNAV or LPV) ☐ RF capability
All IFR Operations		☐ Early in the mid term, RNAV 2 and RNAV 1, supported by GNSS ☐ RNAV (GPS) approach capability (LNAV at minimum)	☐ RNAV (GPS) approach capability (LNAV/VNAV or LPV)*

Figure 3

While these policy expectations have been generally achieved by Mainline fleets, they have gone largely unmet by the Regional fleets; however, with the introduction of Embraer's more fully equipped ERJ–170/190 series and more recent deliveries of CRJs, Regional aircraft capabilities have begun to match Mainline equipage.

In summary, a cost/benefit case was never necessary to justify LNAV/VNAV capability on mainline aircraft because aircraft OEMs delivered it as standard equipment. A market shift coincided with the development of Regional aircraft, so the equipment shifted to less capable LNAV systems, failing to meet policy planning expectations, old and new.

Prior to the COVID–19 pandemic, the market was trending away from older, smaller, less capable Regional aircraft as their age progresses well into the latter years of their expected service life; however, the pandemic has driven many working professionals away from the larger cities in favor of tele-commuting from more remote areas. Where the smaller aircraft were only very recently being parked with little expectation of their return, they are now not only returning to the fleet, but are now in increasingly greater demand to serve these trending, newly popular smaller markets.